Bitter Flavor In Carrots

II. Progress Report on Field and Storage Experiments

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BITTER FLAVOR IN CARROTS

II. Progress Report on Field and Storage Experiments

JOHN D. ATKIN

Abstract

BITTERNESS in carrots that have been stored for some time after harvest has become a serious problem in recent years. This bulletin is published as a progress report to make results of field and storage experiments conducted in 1953–54 and 1954–55 available to all those interested in the problem.

Extensive variety trials in 1953 and 1954 indicated very little difference, if any, in the susceptibility of strains and varieties. However, extreme differences between individual roots indicated that either genetic or micro-environmental factors may be operating in the development of the bitterness.

Carrots grown on the intensive vegetable areas of New York State on muck and sandy soil in 1953 and 1954 were considerably more bitter than carrots grown on general farms on upland loam soils.

None of the experimental lots tested were bitter at harvest time.

Carrots rated more than just slightly bitter have been found only after refrigerated storage, and never after common storage. When a large number of lots of carrots was placed in a refrigerated storage under uniform conditions, it was found that some lots became extremely bitter, while other lots remained almost completely free of bitterness. This suggests that some environmental condition or conditions are operating to predispose carrots to turn bitter in refrigerated storage.

The fact that carrots turn bitter in cold storage and not in common storage indicates that even after the carrots are predisposed to turn bitter, they will actually turn bitter only under certain storage conditions. Thus, it appears that bitterness is due to an interaction of environmental conditions both before and during storage.

Introduction

DURING the last few years a serious flavor problem has become apparent in carrots used for processing. It is difficult, if not impossible, to determine just when the problem first occurred. One idea prevalent in the carrot industry is that the carrots have always been subject to this off-flavor, but that it has only become noticeable with the improved quality control practices of the last few years. The other theory is that the problem has actually developed or become much

worse in the last few years. It was first noted by the baby food processors in New York about six or eight years ago. Yamaguchi, Howard, and McNelly (17)[1] state that it was noted in California during the winter of 1950, but the problem has not been especially serious there.

The flavor has been described as "hot," "bitter," quinine-like," "soapy," and other like terms. The term "bitter" will be used to describe this flavor in this publication, as the term appears to be more nearly correct than the others mentioned and has been more widely used. When the bitter carrots are eaten raw, they leave a lingering bitter taste in the mouth which remains even if nonbitter carrots are eaten following the bitter.

Carrots affected with the bitter flavor show no external symptoms, thus bitterness can be detected only by tasting or by an objective measure which has been developed by Sondheimer, Phillips, and Atkin (13).

Yamaguchi, Howard, and McNelly (17) found that bitter carrots had a lower alpha carotene content than nonbitter samples and suggested that the bitter principle may be breakdown products from carotenoids. They found only a minute difference in total sugars between bitter and nonbitter samples, and thus it appears that bitterness is not due to a deficiency of total sugars.

Hervey and Schroeder (8) found that carrots infected with aster yellows virus developed an astringent off-flavor. However, this astringent off-flavor is considered to be distinct from the bitterness discussed here. Evidence concerning this point will be presented later.

The problem has become very serious to the entire carrot industry of New York and other carrot-growing areas during the last few years, and thus investigations to determine the cause and control have been undertaken. This bulletin is published as a progress report to make the results of field and storage experiments available to all those interested in the problem. The results reported are not regarded as a solution to the problem and research is being continued.

1953–1954 Experiments

Method of Preserving Samples

All of the samples of carrots from the 1953 growing season were stored in a commercial refrigerated storage plant at Geneva. The storage temperature was 32° to 33° F. This storage period was to allow the bitterness to develop, for it had been observed that the bitter problem became more serious after storage. After storage it was neces-

[1]Refers to Literature Cited, page 29.

sary to preserve the carrots in such a way that the bitterness would not change in the time it took to conduct the tests necessary to determine the degree of bitterness. Experience of commercial processors indicated that processing did not alter the bitter flavor, and that the flavor did not change in the processed product. Therefore, the carrots were preserved by canning them in the pilot plant of the Station's Department of Food Science and Technology.

Because the bitter flavor has been especially objectionable in pureed baby food, it was considered that processing in this form would give a better measure of bitterness than other forms of processing.

The process was as follows: A 6-kilogram sample was weighed and peeled for 1 minute in an abrasion peeler, after which the carrots were hand trimmed and then steamed for 40 minutes at 212° F. Next, the carrots were ground in a hammermill and then pureed by means of a finisher, using a 0.0030 screen. The pureed material was then heated to 190° F, with constant stirring to prevent caramelization of sugars, and placed in "carrot enamel" cans and sealed. The sealed cans were then cooked in a retort at 240° F for 75 minutes. Following cooking, the cans were cooled in cold water.

Method of Detecting Bitterness

During the 1953–54 season the carrots were all rated organoleptically. The organoleptic tests were conducted in the Station's taste testing laboratory. The taste panel consisted of 20 people who were chosen for their ability to detect bitterness in carrots. Because of the fact that it was necessary to taste carrots over a period of several weeks, it was impossible for all members of the panel to be present for every session of tasting, but in no case were samples tasted by less than 15 members of the panel.

At each session, the panel judged the flavor of four unknown samples, using a scale from 9 (extreme bitterness) to 0 (complete lack of bitterness) in comparison to a nonbitter standard sample which was arbitrarily assigned a score of 2, so that panel members could rate samples less bitter than the standard if they so desired. The nonbitter standard of comparison was prepared from one large lot of carrots harvested and canned in November. The panel members were reluctant to rate samples better than 2, and a mean score of 3 or below indicated that the sample was excellent and a score of 7 or above indicated that the sample was extremely bitter.

Although organoleptic scoring is not an exact science, it was found that by using this method the agreement between average scores given to the same samples repeated at infrequent intervals was very good.

Thirty-eight samples were repeated and the greatest difference in scores given to a single sample was 1.4. The r value indicating degree of correlation between the scores given at two different times was 0.94.

Because very little was known about the rate at which the bitterness developed in storage, carrots from the 1953 growing season were canned at two different dates. Each lot was divided and one-half was canned between December 14 and 23, 1953 (hereafter termed December canning), and the other half between January 25 and February 3, 1954 (hereafter termed January canning). Both cannings of each sample were tested to determine if the longer storage period allowed the carrots to become more bitter. On the average, carrots canned in January were slightly more bitter than those canned in December. The average scores of the two cannings varied between 3.0 and 6.8, and a score above 6 indicated a very bitter sample, while a score below 4 generally indicated a very good sample.

Farm Survey

When the investigations were started in 1953, very little was actually known about the problem. As a preliminary step designed to obtain leads for further research, a cooperative project was set up between the Experiment Station and individual carrot growers who had contracted to grow carrots for baby food processors, whereby the growers were to record on a sheet furnished by the Experiment Station the following data: Date of planting; variety; strain or lot number; source of seed; soil type; chemical weed control, including dates of application and amounts applied at each application; source of the oil used; disease conditions in the field; insecticides used; soil fumigations in the last three years and chemicals used; previous crops for the last four years; fertilization program, including amount and analysis of each application; cover crops plowed under, drainage conditions in the field; date of harvest; date placed in storage; and type of storage. Fieldmen from different baby food companies assisted growers in filling out the data sheets during the growing season.

At harvest time a 1-bushel sample was collected from each field and these samples stored temporarily in commercial cold storage houses in the areas in which the carrots were grown. The samples were then collected and placed in refrigerated storage at 32° F at Geneva. After storage the carrots were canned and subsequently rated for bitterness by the taste panel and an attempt made to correlate the different cultural practices with bitterness.

The type of experiment outlined above is far from critical, as one never knows how accurately the data are recorded and growers often

fail to answer some of the questions or give ambiguous answers. In addition, environmental conditions are never constant from area to area or even from field to field, so that not one but many factors are variable. No statistical analysis is justified and thus the results are presented merely to give an indication of possible leads for further research.

Date of planting.—The date of planting ranged from April 3 through June 23, but nearly all of the carrots were planted between May 1 and June 10 (Table 1). Most of the fields were harvested in the latter part of October and the carrots planted early generally had a longer growing season and reached the hot weather at a different stage of maturity. These factors might possibly affect bitterness.

Table 1.—The Effect of Different Dates of Planting on Bitterness.

Planting dates	Number of fields	Range of bitterness	Average* bitterness
Apr. 1 through Apr. 30	2	4.9–6.4	5.7
May 1 through May 10	7	3.1–5.3	4.7
May 11 through May 20	8	2.9–6.1	4.9
May 21 through May 31	15	3.1–6.4	5.0
June 1 through June 10	10	3.6–6.8	5.6
June 11 through June 30	7	3.9–5.9	4.8

*Each average given is the average of all lots in the category and not the mean of the extremes.

The data fail to suggest that there is a correlation between the date of planting and bitterness, although such a possibility is not eliminated.

Variety and strain or lot number.—The carrots planted for processing were all of the Chantenay type with most of them being different strains of Red Core Chantenay. A few of the newer strains of Chantenay were also planted. The growers generally did not know strain or lot numbers, and thus it was impossible to compare different strains of Red Core Chantenay. There was no obvious difference between Red Core and the newer strains of Chantenay.

Soil type.—Several different soil types were listed, but these can all be grouped roughly into three categories: Muck, sandy soil of the Greece area, and the heavier loam soils of the Geneva area. Table 2 summarizes the effect of soil type on bitterness.

Table 2.—The Effect of Soil Type on Bitterness.

Soil type	Number of fields	Range of bitterness	Average bitterness
Sandy	13	4.3–6.8	5.8
Muck	28	4.2–6.8	5.4
Loam	19	2.9–6.3	4.4

The data illustrate the fact that carrots grown on sandy and muck soils were never better than intermediate in bitterness, and that on the average they were considerably more bitter than the carrots grown on loam soils. Of the 19 fields of carrots grown on loam soil, 11 had organoleptic ratings below 4.2, which is the lowest rating given to any of the sand or muck carrots. It is very possible that this apparent difference between the soil types could be due to some other environmental factor. However, there is the possibility that some nutritional or other environmental factor peculiar to muck or sandy soils is affecting the bitterness of the carrots.

Number of oil sprays applied for weed control.—The fields of carrots received from one to three applications of oil spray for weed control. No farmers reported that oil was not applied. The results are given in Table 3.

Table 3.—The Relationship Between Number of Oil Sprays and Bitterness.

Number of applications	Number of fields	Range of bitterness	Average bitterness
1	17	3.9–6.8	5.2
2	36	2.9–6.7	5.2
3	3	4.8–5.3	5.0

The second and third applications of the oil spray were applied considerably later in the season than the first, and yet there seems to be no relationship between extra applications of oil later in the season and bitterness.

Source of oil spray material.—Most growers buy the oil used for weed control from three of the major petroleum companies. It has been suggested that the bitterness could possibly be due to impurities found in the material furnished by one or more companies. Table 4 summarizes the effect of the oil from the different sources on bitterness.

Table 4.—Relationship of Source of Oil for Weed Control and Bitterness.

Company	Number of fields	Range of bitterness	Average bitterness
A	12	2.9–6.8	4.6
B	7	3.8–5.9	4.6
C	32	3.1–6.8	5.5

The data indicate that, on the average, carrots sprayed with oil from company C were more bitter than those sprayed with oil from the other companies, but it will be noted that some of the carrots sprayed with this oil were very good. The fact that carrots sprayed with oil from company C are more bitter than carrots sprayed with oil from the other two companies could be due to the fact that company

C sold the bulk of the oil used in the areas where the carrots were generally more bitter, and in those areas there seemed to be no difference between carrots sprayed with the oil from the different companies. The fact that the number of applications of oil, applied as reported earlier, did not affect bitterness lends support to the idea that bitterness is not due to impurities found in the oil supplied by a certain petroleum company.

Disease conditions in the field.—The only disease conditions reported during the year were slight infestations of aster yellows in nearly all fields. Carrots affected with this disease will produce an off-flavored processed product as reported by Hervey and Schroeder (8). However, this flavor is generally considered to be different from the bitterness herein discussed. In order to eliminate the possibility that aster yellows would affect the bitterness ratings, all carrots showing symptoms of the disease were discarded at harvest time.

Insecticides applied.—Some growers apply insecticides for the control of the six-spotted leafhopper which transmits the carrot yellows disease. DDT is generally applied, but Parathion has been used. A total of 13 fields were sprayed during the summer with DDT or Parathion, or mixtures of the two. Bitterness in the carrots from these fields ranged from 2.9 to 6.7 with an average of 5.2, which suggests that insecticides had very little effect on the tendency to become bitter.

Soil fumigation.—Only five fields of carrots were planted on land which had been fumigated in the last three years. These fields were all in the Greece area where the carrots were generally bitter, but there was no observable difference between carrots grown on fumigated soil and those grown on nonfumigated land.

Preceding crops.—It was thought that carrots could possibly be affected by crops grown the previous year or by insecticides, fertilizers, or fungicides applied to those crops, and thus a record was made of previous crops. Carrots in New York are grown in many rotations, but only two crops were represented often enough as previous crops to be considered. On many of the muck farms carrots are grown for several years in a row, or following onions. Table 5 gives the effect of onions and carrots on following crops of carrots.

Table 5.—The Effect of Onions and Carrots on the Bitterness of Following Carrot Crops.

Previous crop	Number of fields	Range of bitterness	Average bitterness
Carrots	26	2.9–6.6	5.0
Onions	6	4.8–6.1	5.4

It will be noted that in the 26 fields on which carrots were grown as the preceding crop there is a complete range of bitterness, and that the mean bitterness rating is very similar to the mean of all the fields sampled. While only six fields had onions as the preceding crop, there is nothing to suggest that onions could in any way be responsible.

Fertilization.—One of the first possibilities suggested as a cause of bitterness was fertilization. This could be in the form of applications which are either too heavy or too light, or due to improper balance. All growers were asked to record the amount of fertilizer applied. When the data sheets were tabulated it was noted that there was a complete range of fertilizer practices. In an effort to determine if fertilizer had any effect on bitterness, the fields were divided into two classes, those with a bitterness rating of 5.5 or above and those with a rating of 4.5 or lower. After the above classification was made the amount of the different fertilizer elements was determined and the range and mean amount applied per acre calculated. Table 6 gives these data.

Table 6.—Amount of the Major Fertilizer Elements Applied to Fields Which Produced Bitter and Nonbitter Carrots.

Fertilizer elements	Pounds applied per acre	
	Range	Average
Relatively Bitter Crops (23 Lots Ranging Between 5.5 and 6.8 in Bitterness)		
N	0–172	75.4
P_2O_5	0–300	134.5
K_2O	0–300	140.7
Relatively Nonbitter Carrots (15 Lots Ranging Between 2.9 and 4.5 in Bitterness)		
N	0–80	58.7
P_2O_5	60–180	121.3
K_2O	30–300	130.3

The data show that both bitter and nonbitter carrots were produced on fields which were very heavily fertilized or very lightly fertilized. Some of the bitter carrots were actually produced on land which received no commercial fertilizer. The mean amount of fertilizer used on the fields which produced the most bitter carrots was not greatly different from that used on the fields which produced the carrots that were most nearly free of bitterness. It may be possible that different forms of fertilizer could have an effect on bitterness, but it seems improbable that the amount of fertilizer has any great effect.

Cover crops.—On most of the farms cover crops were not plowed under, and farmers using cover crops used several different crops so

that it is impossible to get a comparison between any two cover crops. Table 7 gives the relationship between all cover crops plowed under and bitterness.

TABLE 7.—THE RELATIONSHIP BETWEEN COVER CROPS PLOWED UNDER AND BITTERNESS.

TREATMENT	NUMBER OF FIELDS	RANGE OF BITTERNESS	AVERAGE BITTERNESS
Cover crop	12	2.9–6.7	4.4
No cover crop	45	3.1–6.8	5.4

It will be noted that, on the average, fields which had no cover crop plowed under produced carrots more bitter than those produced on fields where a cover crop was plowed under. However, both very bitter and nonbitter carrots were produced on fields where cover crops were plowed under, and also where cover crops were not plowed under. The difference in bitterness is probably due to the fact that cover crops were generally used on the upland loam farms and the carrots from these farms were on the average less bitter than carrots produced on the muck or sand farms. The upland loam farms generally produced relatively nonbitter carrots regardless of whether or not a cover crop had been plowed under.

Drainage conditions in the field.—It was very difficult to get reliable information on this point and thus no conclusions can be drawn.

Length of growing season.—Practically all of the carrots were harvested the latter part of October. It was difficult to get the exact date that the sample used in the study was harvested, as farmers would generally say that a field was harvested between two dates and then fail to give the date on which the sample was harvested. Because of the fact that nearly all of the carrots were harvested over a relatively short period of time, it is impossible to draw conclusions regarding harvest date, but by using the harvest and planting dates it was possible to determine the growing season with some degree of accuracy on 44 fields. Table 8 gives the effect of length of growing season on bitterness.

TABLE 8.—RELATIONSHIP OF LENGTH OF GROWING SEASON AND BITTERNESS.

LENGTH OF GROWING SEASON, DAYS	NUMBER OF FIELDS	RANGE OF BITTERNESS	AVERAGE BITTERNESS
120–129	4	4.2–6.0	4.8
130–139	14	3.9–6.8	5.5
140–149	10	2.9–6.7	5.6
150–159	8	3.6–6.3	5.1
160–169	6	3.3–4.9	4.4
170–179	2	3.1–4.2	3.6

The fact that both nonbitter and bitter carrots are found at the different lengths of growing season would indicate that probably the length of growing season is not important in the development of bitterness.

Experiments at Geneva, 1953 Season

In addition to the collections of samples throughout western New York, experiments were conducted at the Experiment Station where environmental conditions could be controlled more accurately.

Length of growing season.—This experiment was planned by Professor C. B. Sayre and the carrots were planted and grown under his direction and then turned over to the author for processing and rating for bitterness. A single strain of the Red Core Chantenay variety was planted on the Experiment Station farm on May 15 and June 15, 1953. These carrots were harvested on three different dates and were placed in refrigerated storage immediately after harvest. Each sample was divided into two lots. One lot was canned in December, 1953, and the other in January, 1954. Thus, six different stages of maturity and six lengths of storage were obtained. The results of this experiment are given in Table 9.

Table 9.—The Effect of Length of Growing Season and Storage Period on Bitterness, 1953.

Planting date	Harvest date	Taste panel rating		
		Dec. canning	Jan. canning	Average
May 15	Oct. 2	6.2	6.9	6.6
May 15	Nov. 2	4.2	5.6	4.9
May 15	Nov. 27	2.6	3.7	3.2
June 15	Oct. 2	6.8	7.0	6.9
June 15	Nov. 2	5.3	6.1	5.7
June 15	Nov. 27	2.4	2.6	2.5

From Table 9 it can be noted that date of planting probably had a rather minor role in the development of bitterness, whereas date of harvest or length of storage decidedly affected bitterness. Carrots harvested October 2 and placed in cold storage until canning in December were very bitter, whereas carrots of the same planting allowed to remain in the field until late November were nonbitter when canned in December and also when canned in January.

Irrigation.—One theory concerning the development of bitterness is that it is due to a drouth period during the growth of the crop. Because rainfall can be expected at any time in New York, it is difficult to conduct experiments to simulate drouth conditions.

The varieties Red Core Chantenay, Long Chantenay, Long Im-

perator, and Nantes were planted in rows in a cold frame so that during the simulated drouth the plants could be covered during rains. The carrots were planted in two sections of the cold frame and when they reached approximately 1 inch in diameter water was withheld from one section for 5 weeks. Unfortunately, the weather was rather cool, and the beds had been overwatered to the point that they never did really dry out, so that the simulated drouth was not severe. After the drouth period was over, the beds were left uncovered and natural rainfall kept the soil very wet. The carrots were harvested November 27 and, after cold storage, were canned during the January canning and subsequently rated by the taste panel.

There was no significant difference in bitterness between drouth vs. normal carrots or between the different varieties. However, the taste panel was generally agreed upon the fact that the carrots from all of the irrigation treatments possessed a very disagreeable off-flavor in addition to the bitterness.

Variety trial.—Twenty-six strains and varieties of carrots were planted July 1 on the Experiment Station farm in a randomized block

Table 10.—Carrot Variety Trial, 1953.

Variety*	Variety No.	Taste panel rating		
		December canning	January canning	Average canning
Long Chantenay	1	4.9	5.6	5.2
Red Core Chantenay	3	3.9	5.0	4.4
Red Core Chantenay	4	4.3	5.4	4.8
Red Core Chantenay	5	3.8	3.6	3.7
Red Core Chantenay	6	2.2	3.1	2.6
Red Core Chantenay	8	4.7	5.8	5.2
Red Core Chantenay	9	5.1	4.8	5.0
Long Chantenay	10	2.1	3.0	2.6
Long Chantenay	11	3.0	2.5	2.8
Imperida	12	3.8	3.8	3.8
Supreme Half Long	13	4.2	4.7	4.4
Royal Chantenay	14	3.2	3.8	3.5
Red Core Chantenay	15	4.8	5.7	5.2
Hutchinson	16	4.5	4.3	4.4
Imperator	17	3.0	3.7	3.4
Tendersweet	18	3.8	3.6	3.7
Nantes	19	3.4	4.4	3.9
Morse's Bunching	20	3.0	3.4	3.2
Red Core Chantenay	22	4.6	5.2	4.9
Long Chantenay	23	3.2	3.0	3.1
Long Imperator	24	4.2	5.0	4.6
Red Core Chantenay	25	3.1	4.2	3.6
Nantes	26	3.9	5.8	4.8
Average		3.8	4.3	—

*Three lots were lost due to rot before the January canning and so those varieties are not included in this table.

design with four replications. The carrots were harvested on November 2 and a composite sample was made of the four replications of each variety for storage and subsequent canning and evaluation for bitterness. The composite sample was made by harvesting the four replications in separate containers and then systematically taking single carrots from each container in rotation and placing them in a fifth container, so that the different replications would not be stratified in the composite sample. The composite samples were then placed in refrigerated storage and each sample divided into two lots. One lot was canned in December and one lot in January. The results of this variety trial are given in Table 10. Although the strains are not identified in the table, each strain is different from every other strain.

None of the carrots turned extremely bitter, rather the samples ranged from intermediate to very good. Although there are some differences between strains; within varieties, both good and intermediate strains were found. Carrots canned in January were, on the the average, slightly more bitter than those canned in December.

1954–1955 Experiments

Experimental

Storage.—When the carrots grown in the summer of 1954 were harvested in late October, samples of all lots were placed in a commercial refrigerated storage. In addition, samples of 10 lots were placed in common storage and samples of 26 lots were canned within 2 weeks after harvest. All samples placed in storage were canned between January 3 and 12, 1955. Only one canning was made.

Processing procedure.—The processing method used in the 1953–54 experiments was slow and tedious. In addition, it was rather difficult to heat the pureed product to 190° F and it was suspected that some caramelization of sugars might have occurred. In order to overcome these objections the canning procedure was modified as follows: Six-kilogram samples were washed and boiled for 5 minutes to loosen the skin. They were scraped by hand and then diced. Following thorough mixing, the diced material was placed in No. 2 "carrot-enamel" cans and enough water added to fill the containers. They were then closed under a vacuum in a commercial sealer which automatically regulated the head space. The cans of carrots were cooked at 240° F for 40 minutes and then cooled in cold water.

Flavor evaluation.—The samples were rated by a taste panel as in the 1953–54 experiments, and also by the objective method of testing

for bitterness developed by Sondheimer, Phillips, and Atkin (13). The samples were prepared for tasting by passing them through a kitchen grinder, followed by thorough mixing.

The scoring with the objective method is slightly different from the scoring with the organoleptic method. That is, a sample which is completely free of bitterness would be rated at 0.0 by the objective method and 0.0 by the organoleptic test, but an extremely bitter sample would be rated at approximately 4 or 5 by the objective method and 9.0 by the organoleptic test. The above values are theoretical. Actually, an organoleptic rating of 3.0 or below or an objective rating of 0.4 or below would indicate that the sample was excellent, while an organoleptic rating of 7.0 or above or an objective rating of 3.0 or above indicates an extremely bitter sample.

Results, 1954 Season

Variety trials.—Results of the 1953 work indicated that carrots grown on sandy or muck soils might be more subject to bitterness than those grown on an upland loam. Further, it was noted that differences existed between strains of varieties. In the spring of 1954, 48 strains and varieties were planted on sandy soil at Greece, N. Y., and 32 of these same strains and varieties were planted on muck and also on upland loam soil at Seneca Castle, N. Y. The trials were planted in commercial carrot fields and received the same care as was given to the commercial field. All three variety trials were laid out in a randomized block design with four replications. When the carrots were harvested in late October, a composite sample was made from the four plots of each variety at each farm, according to the method outlined earlier, for storage and subsequent tests to evaluate bitterness.

Samples of all lots were placed in a commercial refrigerated storage, samples of 10 lots were placed in a common storage at the Experiment Station, and samples of 26 lots were canned within 2 weeks after harvest.

Table 11 gives the bitterness of the different varieties following cold storage as measured by the taste panel and Table 12 the results as measured by the objective test. These tables contain only the varieties and strains common to all three locations. Five lots were lost due to rotting in storage; consequently, only 27 strains and varieties are given in the tables.

The data presented in Tables 11 and 12 indicate that there is not perfect agreement between the two methods of measuring bitterness. It will be noted that when the organoleptic method is considered, there is no significant difference between varieties and that the dif-

TABLE 11.—BITTERNESS OF CARROT VARIETIES FOLLOWING REFRIGERATED STORAGE AS MEASURED BY THE ORGANOLEPTIC METHOD.

VARIETY	VARIETY No.	BITTERNESS			
		Sandy soil	Muck soil	Loam soil	Average
Red Core Chantenay	3	4.8	7.2	5.6	5.9
Red Core Chantenay	4	6.2	7.6	4.6	6.1
Red Core Chantenay	5	6.7	7.6	6.9	7.1
Red Core Chantenay	6	6.2	6.9	6.5	6.5
Red Core Chantenay	7	6.8	7.9	4.8	6.5
Nantes Imp. Coreless	26	7.6	8.1	4.4	6.7
Nantes Strong Top	27	7.0	7.6	3.8	6.1
Morse's Bunching	29	6.7	6.7	5.7	6.4
Touchon	30	6.4	7.4	5.1	6.3
Red Core Chantenay	31	6.6	6.8	6.2	6.5
Chantenay	33	6.9	7.6	5.5	6.7
Red Core Chantenay	34	6.8	7.5	5.6	6.6
Danvers Red Core	35	6.0	8.0	5.1	6.4
Imperida	37	4.6	7.2	2.3	4.7
Red Core Danvers	39	6.4	6.9	3.7	5.7
Long Imperator	41	4.2	8.1	4.1	5.5
Chanticleer	42	8.0	7.2	5.0	6.7
Red Core Chantenay	43	6.4	7.2	4.5	6.0
Chantenay	45	5.4	7.8	2.9	5.4
Royal Chantenay	49	4.1	7.4	5.2	5.6
Corneli's Coreless	52	6.6	6.6	7.1	6.8
Red Core Chantenay	54	5.6	7.7	3.9	5.7
Supreme Half Long	55	6.2	7.4	4.8	6.1
Gold Spike	56	8.0	6.6	3.5	6.0
Nantes Strong Top	60	3.3	6.6	3.6	4.5
Nantes	63	6.7	6.0	5.0	5.4
Flakkee	65	7.9	7.6	4.1	6.5
Average		6.2	7.3	4.8	

L.S.D. at 5 per cent level for soil means, 0.5.
L.S.D. at 5 per cent level for variety means, not significant.

ferences between the three soil types are all significant. That is, the loam soil is significantly better than the sandy soil and that the sandy soil is significantly better than the muck. When the objective method is considered it will be noted that there are significant differences between strains and varieties, and that the carrots from muck soils are significantly more bitter than carrots from sandy or loam soils, but that there is no significant difference between the sandy and loam soils.

A description of the three trials may help to explain possible reasons for the discrepancies noted above. The carrots planted on the sandy soil came up very well and a good normal crop was produced. The carrots planted on the muck soil came up and a few days later hot, dry winds killed the young seedlings and the entire field was replanted on July 3. Soon after this second planting emerged it was severely damaged by hot, dry winds, but it was so late in the

TABLE 12.—BITTERNESS OF CARROT VARIETIES FOLLOWING REFRIGERATED STORAGE AS MEASURED BY THE OBJECTIVE METHOD.

VARIETY	VARIETY No.	BITTERNESS			
		Sandy soil	Muck soil	Loam soil	Average
Red Core Chantenay	3	2.9	5.3	4.5	4.2
Red Core Chantenay	4	1.8	3.4	2.2	2.5
Red Core Chantenay	5	3.7	3.5	4.2	3.8
Red Core Chantenay	6	2.5	3.9	3.5	3.3
Red Core Chantenay	7	3.4	3.4	1.4	2.7
Nantes Imp. Coreless	26	5.4	6.5	3.9	5.3
Nantes Strong Top	27	3.2	5.0	3.2	3.8
Morse's Bunching	29	3.2	3.4	2.5	3.0
Touchon	30	3.2	3.6	5.3	4.0
Red Core Chantenay	31	3.2	3.2	3.4	3.3
Chantenay	33	3.8	3.6	2.5	3.3
Red Core Chantenay	34	4.1	4.4	3.7	4.1
Red Core Danvers	35	2.2	4.4	1.5	2.7
Imperida	37	2.2	4.7	2.9	3.3
Red Core Danvers	39	3.8	3.2	1.3	2.8
Long Imperator	41	2.0	4.3	1.6	2.6
Chanticleer	42	4.4	4.6	4.2	4.3
Red Core Chantenay	43	3.6	5.1	2.3	3.7
Chantenay	45	2.1	3.3	2.1	2.5
Royal Chantenay	49	1.6	3.5	1.8	2.3
Corneli's Coreless	52	3.8	5.2	7.1	5.4
Red Core Chantenay	54	2.2	3.0	1.4	2.2
Supreme Half Long	55	2.1	3.8	2.9	2.9
Gold Spike	56	5.0	3.8	2.3	3.7
Nantes Strong Top	60	1.5	5.3	3.8	3.5
Nantes	63	5.1	4.4	3.9	4.5
Flakkee	65	2.7	2.0	1.4	2.0
Average		3.1	4.1	3.0	

L.S.D. at 5 per cent level for soil means, 0.5.
L.S.D. at 5 per cent level for variety means, 1.5.

season that it was considered too late to replant. The stand was very poor, but the carrots were well covered with soil to prevent the development of green shoulders. Before the carrots on the upland soil emerged, a beating rain fell and this was followed by a dry period which caused a crust to form, and the emergence was very poor. However, the variety trial made up only a small part of the large field of commercial carrots, and the grower reasoned that the crop was sufficiently good to keep rather than to try to replant late in the season. The plants were so thinly spaced that the tops did not shade the plants and the soil was not banked around the plants, so that the top of the root was exposed to sunlight and extreme greening of the shoulders resulted.

Figure 1 shows the correlation between the organoleptic and objective methods of scoring, r = .59. This r value is highly significant, but it will be noted that the correlation is far from perfect. It has been

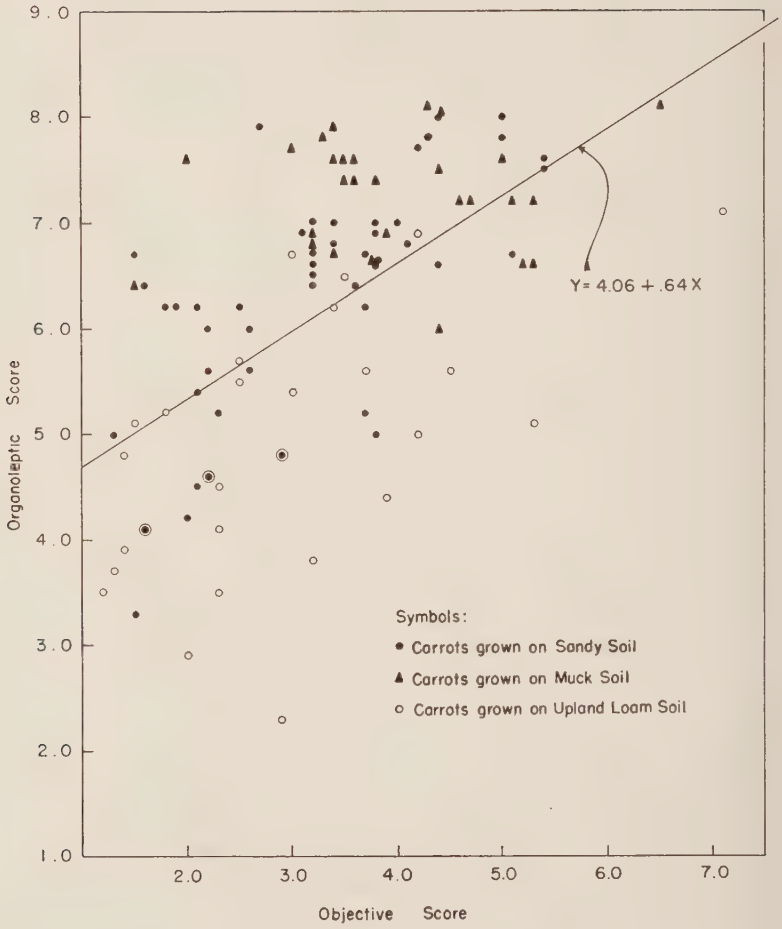

Fig. 1.—Correlation between organoleptic and objective methods of scoring.

previously mentioned that the taste panel is not completely reliable when samples are repeated, and the judgment of the taste panel can possibly be altered by flavors other than bitterness. Further, it has been found (13) that the objective measure is more reliable when the carrots are relatively nonbitter. These carrots were generally very bitter. An examination of Fig. 1 will show that the values of nearly all of the samples from loam soil are below the regression line, and that the few points above the regression line are only slightly above the line. In other words, the taste panel rated these carrots generally better than did the objective test. This may have been just a chance

phenomenon or it may be a real discrepancy due to a factor or factors which are unknown.

Whether the differences between the varieties are statistically significant or not is probably of more academic than practical importance, for all of the carrots turned bitter and were probably too bitter to be used for processing. The differences are actually rather slight, and no varieties could be considered as being free of bitterness.

Varieties 3, 4, 5, 6, and 26 were planted in both 1953 and 1954. A comparison of Table 10 with Tables 11 and 12 will show that the varieties performed differently each year. In 1953, variety 6 was the most nearly free of bitterness in the entire trial; in 1954 it was only intermediate in bitterness.

Bitterness and soil type.—In the 1953 tests it had been noted that carrots grown on muck and sandy soils were generally more bitter than those grown on upland loam soils. The 1954 results showed that carrots grown on the muck soils were more bitter than carrots grown on sandy or loam soils, and as measured organoleptically, carrots grown on sandy soil were more bitter than those grown on upland loam. This last comparison was not substantiated by the objective test.

It should be remembered, however, that only one farm was involved in each case and it is very possible that other factors are involved. For example, the carrots grown on the muck soil were lost due to hot, dry, windy weather, and were replanted on July 3. Thus, at harvest time the carrots were rather small and immature. The stands on the muck and upland soils were very poor as was mentioned previously. These are only two of the factors which might possibly affect bitterness.

Bitterness before storage.—Yamaguchi, Howard, and McNelly (17) reported that the bitterness found in California was traced to certain lots of Red Core Chantenay carrots that had been held at 32° F from 6 to 12 weeks, and that only one bitter carrot had been found in the field at harvest time. There is considerable disagreement among people in the carrot industry concerning the occurrence of bitter carrots in the field. It is certain that all carrots are not completely free of off-flavors at harvest time and some of these off-flavors might be called bitter. Samples of 26 lots of carrots were canned at harvest time, and none of these lots had an objective rating above 0.3 or an organoleptic rating above 2.7. This indicates that these 26 lots were, from a practical standpoint, completely free of bitterness at harvest time. Samples of these 26 lots turned bitter when held in refrigerated storage. Table 13 gives the average bitterness of these 26 lots before and after storage.

Although the data show quite conclusively that the 26 lots were

Table 13.—Bitterness Before and After Storage.

Time of processing	Average bitterness	
	Objective rating	Organoleptic rating
Canned at harvest time	0.2	2.1
Canned following 10 weeks cold storage	3.4	7.1

not bitter at time of harvest, it must be remembered that they came from only three different fields. Consequently, it cannot be stated that bitter carrots never occur in the field.

Bitterness and storage.—Ten varieties which had been grown on sandy soil were each divided into three lots at harvest time. One lot was placed in a commercial refrigerated storage, one lot was canned at harvest time, and the third lot was placed in a common storage at the Experiment Station. This storage is located in a basement and is cooled by opening the doors at night or on cool days and then closing them during warmer periods. When the carrots were placed in this storage, the temperature was about 45° F. It gradually went down to 40° where it was held. The carrots from both storages were canned early in January. Table 14 gives the results of this study.

Table 14.—The Relationship of Storage and Bitterness.

Time of processing	Average bitterness	
	Objective rating	Organoleptic rating
Canned before storage	0.2	2.1
Canned following 10 weeks common storage	0.2	2.8
Canned following 10 weeks cold storage	3.4	7.1
L.S.D. .05	0.6	0.5

The data indicate that carrots which are free of bitterness at harvest time turned extremely bitter in cold storage, but remained free of bitterness in common storage.

A commercial company grew eight strains of Chantenay carrots in variety trials in commercial fields on both muck and sandy soil. Each lot was split into four lots at harvest time and these lots were placed in a farm common storage and in three commercial refrigerated storages. After storage the carrots were canned commercially and were subsequently tested by the objective method at the Experiment Station. The carrots were not rated organoleptically. The results are given in Table 15.

Although the carrots from all three cold storage houses became so bitter that they would be unacceptable in the finished product, those

Table 15.—The Effect of Different Storages on Bitterness.*

	Type of Storage			
	Common	Refrigerated		
		A	B	C
Objective rating	0.52	5.3	3.7	3.4

L.S.D. .05 between refrigerated storage means, 0.8

*Each number is the average of 16 lots of carrots held in the storage indicated.

from cold storage A were significantly more bitter than those from the other two cold storage houses. The carrots from common storage would probably be classified as slightly bitter.

Variation in bitterness from carrot to carrot.—In tasting individual carrots in cold storage, there appears to be considerable variation from root to root. Yamaguchi, Howard, and McNelly (17) reported that in boxes containing bitter roots the bitterness was sporadic and varied from 10 to 90 per cent.

To determine the actual degree of variation between roots, 25 carrots from each of two different ½ bushel lots were processed individually and subsequently tested for bitterness by the objective method. In one lot the ratings ranged from 2.1 to 6.9 and in the other from 1.3 to 13.4. While no carrots were found which were completely free of bitterness, the wide range in bitterness must be considered when samples are being tested so that composite samples large enough to test the entire range of bitterness can be used.

Size of root and bitterness.—One theory which has been advanced as a cause of bitterness is that the carrots used for processing are allowed to become large and overmature, and that bitterness is simply a result of this overmaturity. This idea has been widely circulated and has gained considerable support. The large and small roots in a bushel of Royal Chantenay carrots from the variety trial were sorted out and canned separately. The large carrots were approximately 2½ to 3 inches in diameter and the small roots were approximately 1½ to 2 inches in diameter. After processing the lots were rated for bitterness and the results are given in Table 16.

Table 16.—Relationship of Size of Root and Bitterness.

Size of root	Bitterness	
	Objective method	Organoleptic method
Large carrots	1.6	5.4
Small carrots	2.5	5.5

The above differences are not statistically significant, but they certainly do not favor the idea that large carrots become more bitter than small ones. On the contrary, by both methods the small carrots were rated as more bitter than the large ones.

When the individual carrots were canned to determine the variation from root to root, they were weighed individually. The correlation coefficient was determined for the correlation between size and bitterness of the two 25-carrot samples. The r values were —.21 and —.35, respectively, with a value of .38 necessary for significance at the 5 per cent level. Again, these values are not significant but favor the idea that small carrots show a greater tendency toward bitterness than large ones.

Finally, in the three large experiments conducted in 1954, the carrots grown on the muck soil were the most bitter. Also, they were planted late due to loss of the first seeding and were only slightly larger than bunching carrots at harvest time. Thus, although there is no proof that small carrots show a greater tendency toward bitterness than large ones, the evidence against the idea of bitterness being due to overmaturity and large size appears to be very strong.

Position of bitter principle in root.—Yamaguchi, Howard, and McNelly (17) reported that the bitter principle appears to be concentrated in the phloem tissue and not in the xylem. In preliminary tests the same appeared to be true when carrots were tested here. In order to determine if these differences actually did exist, samples of carrots which had been kept in cold storage were prepared in which the xylem and phloem were separated and canned separately. These samples were tested for bitterness and the results are given in Table 17.

Table 17.—Position of Bitter Principle in the Carrot Root.

Section of root	Bitterness rating	
	Objective method	Organoleptic method
Xylem	0.5	4.6
Phloem	2.6	6.8

The data indicate that the bitter principle is concentrated mainly in the phloem. The organoleptic score for the xylem is higher than would be expected from the objective score, but this can probably be attributed to the fact that the xylem has a strong flavor which was confused with bitterness by some members of the panel. Several panel members complained of the strong flavor of the xylem.

Hervey and Schroeder (8) reported that the carrot yellows disease

affected the flavor of the processed product. The off-flavor was described by them as bitter with an astringent effect that clings to the mouth for some time. This description would also fit the off-flavor known as bitterness. They did not mention the part of the carrot affected by the off-flavor, but in personal conversation they have stated that the off-flavor is concentrated in the core.

The data in Table 17 indicate that the bitter principle is concentrated in the phloem. This is added evidence that the off-flavor caused by carrot yellows is different than the bitterness described in this publication.

Sodium and bitterness.—Truog, Berger, and Attoe (14) reported that carrots grown in nutrient solutions in which sodium was absent were not as sweet as those grown in solutions containing sodium.

Bernstein and Ayers (2) noted that carrots grown in soils of high salinity were better flavored than those grown in low saline soils. They did not mention bitterness.

Preliminary experiments were conducted in both nutrient solution cultures in the greenhouse and in soil in the field. The nutrient culture experiments were set up using Hoagland's (9) solution No. 2 as a check. One treatment consisted of this solution plus 5 cc per liter of a molar Na_2SO_4 solution. The other treatment consisted of the basic solution plus 5 cc per liter of molar NaCl solution. Each treatment was repeated in eight different crocks, with three or four carrots per crock.

The carrots thrived and were harvested when between 2 and 2½ inches in diameter on May 14, 1954. They were stored in refrigerated storage at 32° to 33° F, until August 31 when they were processed and rated for bitterness. Carrots from all three treatments were quite bitter and the sodium treatments did not aid in the prevention of bitterness.

Field experiments were conducted in cooperation with Professor Sayre on two fields which had produced very bitter carrots. Since the experiments were preliminary, the treatments were not replicated. The different treatments (Table 18) were applied as side dressings about 2 inches deep and 3 inches to the side of the row.

After the carrots were harvested in late October they were stored under refrigeration for approximately 10 weeks and then processed and subsequently rated for bitterness. The objective scores (Table 18) indicate that all of the carrots were very bitter and that the different treatments were not effective in reducing bitterness.

Color and bitterness.—Carrot processors have observed that there

TABLE 18.—SODIUM TREATMENTS AND THEIR EFFECT ON BITTERNESS, 1954.

Sodium treatments				
Treatment No.	Material	Pounds per acre	Date applied	Bitterness objective rating
	Field 1			
1	Check	—	———	2.5
2	Sodium nitrate	300 300	Aug. 16 Sept. 8	3.3
3	Sodium chloride	200 200	Aug. 16 Sept. 8	3.1
4	Ammonium nitrate	150 150	Aug. 16 Sept. 8	2.6
	Field 2			
1	Check	—	———	5.4
2	Sodium nitrate	300	Aug. 23	5.7
3	Sodium chloride	200	Aug. 23	4.0
4	Ammonium nitrate	150	Aug. 23	5.5
5	Sodium nitrate	300 300	Aug. 23 Sept. 15	5.3
6	Sodium chloride	200 200	Aug. 23 Sept. 15	5.3
7	Ammonium nitrate	150 150	Aug. 23 Sept. 15	5.3

appears to be a negative correlation between deep orange color and bitterness, or that bitter carrots had a paler color than nonbitter carrots. Ten lots of carrots from the variety trials were each divided into three samples. One sample was canned at harvest time, the second was canned following refrigerated storage, and the third was canned following common storage. The length of storage was the same for both storage treatments. After processing, the samples were rated for bitterness objectively and organoleptically and color was measured by the Hunter Color Difference Meter. The a/b rating is a measure of the degree of redness of the orange color as a measures the relative redness of the sample and b the yellowness. Table 19 gives the average bitterness ratings of these 30 lots and also the a/b ratings following processing. Each number in the table is the average of 10 lots.

The data indicate that the carrots held in refrigerated storage became bitter, and also became more yellow in color; whereas, the carrots

Table 19.—Relationship of Color and Bitterness.

Sample processed	Average ratings		
	Objective	Organoleptic	*a/b*
At harvest time	0.2	2.1	0.99
Following refrigerated storage	3.4	7.1	0.91
Following common storage	0.2	2.8	1.04
L.S.D. .05	0.6	0.5	0.08

from the same lot kept in common storage remained nonbitter and became more nearly red in color when compared with the samples canned at harvest time.

The carrots grown on the three soil types differed significantly in bitterness. The order of these three soil types in relation to increasing bitterness was: upland loam, sand, and muck soils. The order in regard to increasing redness was just the opposite.

Yamaguchi, Howard, and McNelly (17) found that bitter carrots have a lower alpha-carotene content than nonbitter carrots, and have surmised that bitterness may be caused by metabolic products of the carotenoids.

This apparent relationship between color and bitterness may have a definite bearing on the problem, or it may be simply a coincidence where bitterness and loss of color are not directly related but are caused by the same metabolic factors.

Emsweller, Burrel, and Borthwick (5) found that there was a very high correlation between carotene and a colormeter reading on extracted pigment, indicating that the orange pigment is largely carotene. Carotene content varies between different genetic lines and is profoundly affected by environmental conditions in the field, and also by storage (1, 3, 4, 5, 6, 7, 10, 11, 12, 15, 18).

Summary and Discussion

Cultural practices employed by carrot producers in New York vary widely. The degree of bitterness developed by different lots of carrots also varies all the way from extreme bitterness to complete lack of bitterness.

A farm survey was conducted in 1953 to try to correlate bitterness with some specific cultural practice. In this survey it was found that the date of planting varied between April 3 and June 23. From one to three applications of oil were applied to control weeds. This material was obtained from several different petroleum companies, but the bulk of the oil was supplied by three major firms. Five fields

had been fumigated within the past three years. A wide range of crops had been grown in the rotation the previous year, but on 26 fields carrots had been grown the preceding year and on 6 fields onions had been the preceding crop. Thirteen fields were sprayed with various insecticides for the control of the six-spotted leafhopper which spreads the carrot yellows disease. Nitrogen, phosphorus, and potash fertilization varied from none to very large amounts. On 12 fields various cover crops were plowed under, while on 45 fields it was reported that no cover crop was used. The above factors appear to have had no effect on the development of bitterness as extremely bitter and also nonbitter carrots were found under all conditions.

An experiment was conducted to determine the effect of irrigation on bitterness. An artificial drouth was created during the middle of the growing season by planting carrots in a cold frame and then covering one section during storms. After the "drouth period" was over the carrots received normal rainfall which kept the soil very wet until the carrots were harvested. There was no difference in bitterness between carrots subjected to drouth and those receiving adequate moisture, but the taste panel indicated that there was a serious off-flavor in addition to bitterness in all of the carrots. This may possibly be due to the extremely wet soil conditions for the period just preceding harvest.

Experiments to determine the effect of sodium indicated that lack of this element is not responsible for the development of bitterness.

In the farm survey of 1953 there was a range in length of the growing season from approximately 125 to approximately 175 days. There appeared to be very little effect of the length of growing season on bitterness, except that the few fields which had the longest growing season were not extremely bitter. However, in experiments at Geneva, where the same seed lot of carrots was planted on May 15 and June 15 and harvested on October 2, November 2, and November 27, it was found that carrots harvested on October 2 were very bitter after approximately 10 weeks' storage, whereas those harvested on November 27 were practically completely free of bitterness after approximately 8 weeks' storage. It is impossible to determine just what factors are responsible for this difference for many factors differed. Some differences are: length of growing season, environmental conditions in the field prior to harvest and at harvest, and possible environmental conditions in the refrigerated storage.

In the farm survey in 1953, and also in the 1954 experiments, it was found that the carrots grown on muck and sandy soils were generally more bitter following refrigerated storage than were carrots

grown on upland loam soils. This apparent correlation between soil type and bitterness could be due to any number of factors. The fact that the muck and sandy soils are intensive vegetable areas, whereas the upland loam soils are used more for general farming, might suggest that a deficiency of minor elements may be responsible.

Extensive variety trials were conducted in both 1953 and 1954. The results indicate that the differences between strains and varieties are very slight, if indeed, the differences are actual and not due to chance variation. In any event the differences are so slight that they are not commercially significant, and the problem cannot be solved by using any strains or variations which were tested.

The extreme difference found between individual roots of the same lots suggests that either genetic or micro-environmental factors are operating. At first glance it may appear that it is contradictory to say that there is no difference between strains or varieties, but that there could be genetic differences between individual roots in regard to the bitterness. However, carrots are highly cross pollinated and therefore very heterozygous genetically. A strain is simply a collection of a large number of biotypes. Therefore, the average of the biotypes in one strain could be very near the average of the biotypes in any other strain, but within any strain certain biotypes could be genetically resistant to bitterness. If the variation from root to root is due to genetic causes, it may be possible to breed carrots which are resistant to bitterness.

It was mentioned above that the extreme differences between roots could possibly be due to factors of micro-environment. There is no evidence concerning what factors might be involved, but they could occur in the field, at harvest time, or even in refrigerated storage.

There was a consistent tendency, although in no case statistically significant, for the smaller and more immature carrots to be more bitter than large or fully mature carrots. This, coupled with the possibility that carrots which have a long growing season are less likely to become bitter than those with a short growing season, would suggest that immaturity might be a contributing factor in the development of bitterness in refrigerated storage.

The fact that carrots which turned bitter became paler in color might suggest that the bitterness is due to metabolic products of the carotenoids. However, it is also possible that there is no connection between bitterness and loss of color, except that both are favored by the same conditions in storage.

None of the experimental lots tested have been bitter at harvest time. This is not to say that bitter carrots can never occur in the field.

It is definitely true that carrots can develop a very strong flavor, or even off-flavor, in the field. In tasting it would be very possible to confuse flavors, and it is also possible that bitterness does occur in the field.

In this work, carrots which have been rated more than just slightly bitter have been found only after refrigerated storage. There is considerable variation in the degree of bitterness developed by different lots of carrots which have been given, as far as can be determined, exactly the same refrigerated storage treatment. Some lots of carrots have actually remained almost completely free of bitterness in cold storage. This fact forces the conclusion that some factor or factors other than storage are operating to predispose carrots to turn bitter. Since, in the variety trials, all strains and varieties reacted essentially the same, it would be difficult to conclude that genetic factors are responsible. The factors which are responsible could be due to any one of many different environmental conditions. Evidence gained so far indicates that it could be due to soil conditions or to length of growing season. However, there is no proof that these are the factors involved, and any one of many others could be responsible.

The fact that the experimental carrots have never turned more than just slightly bitter in common storage, whereas carrots from the same lots have turned very bitter in refrigerated storage, forces the conclusion that conditions in refrigerated storage will cause carrots which are predisposed to become bitter to develop the off-flavor. The common storages are not refrigerated and are cooled by opening the doors during cool periods and then closing them during warmer periods. This usually amounts to closing the doors during the day and opening them during the night. With this type of cooling the field heat is removed rather slowly and the temperature remains relatively high for a considerable period, while in refrigerated storage the carrots are cooled rather quickly to 32° to 33° F, then held at that temperature. Also, in refrigerated storage, a definite effort is made to prevent excess ventilation, while in common storage the method of cooling insures adequate ventilation. Probably there are many other less obvious differences.

The idea that cold storage could cause bitterness to develop is not without precedent. Many products suffer "chilling injury" caused by abnormal metabolism at low temperatures. Wright, Rose, and Whiteman (16) list 26 different crops which suffer chilling injury at low temperatures. Among the crops listed are apples, snap beans, cucumbers, eggplants, melons, okra, peppers, potatoes, squash, sweet potatoes, and tomatoes. It is common knowledge that in the potato, starch

is converted to sugar at temperatures below 40° F. At temperatures below 55° mature green ripe tomatoes fail to develop normal red color. When the physiological processes of many other crops can be upset by low temperatures, it is not illogical to assume that the same thing could occur in carrots.

Although carrots will remain nonbitter in common storage, this is not advanced as a final solution of the problem, for the higher temperatures found in this type of storage in the fall are conducive to the development of rots. Because of this, common storage can be relied upon only for relatively short periods. The final answer to the problem may possibly be one or a combination of the following: Discover methods of altering environmental conditions before storage so that the carrots will not be predisposed to turn bitter; breed carrots resistant to bitterness; or alter conditions in refrigerated storage so that the bitterness will not develop. Research is proceeding along these lines.

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